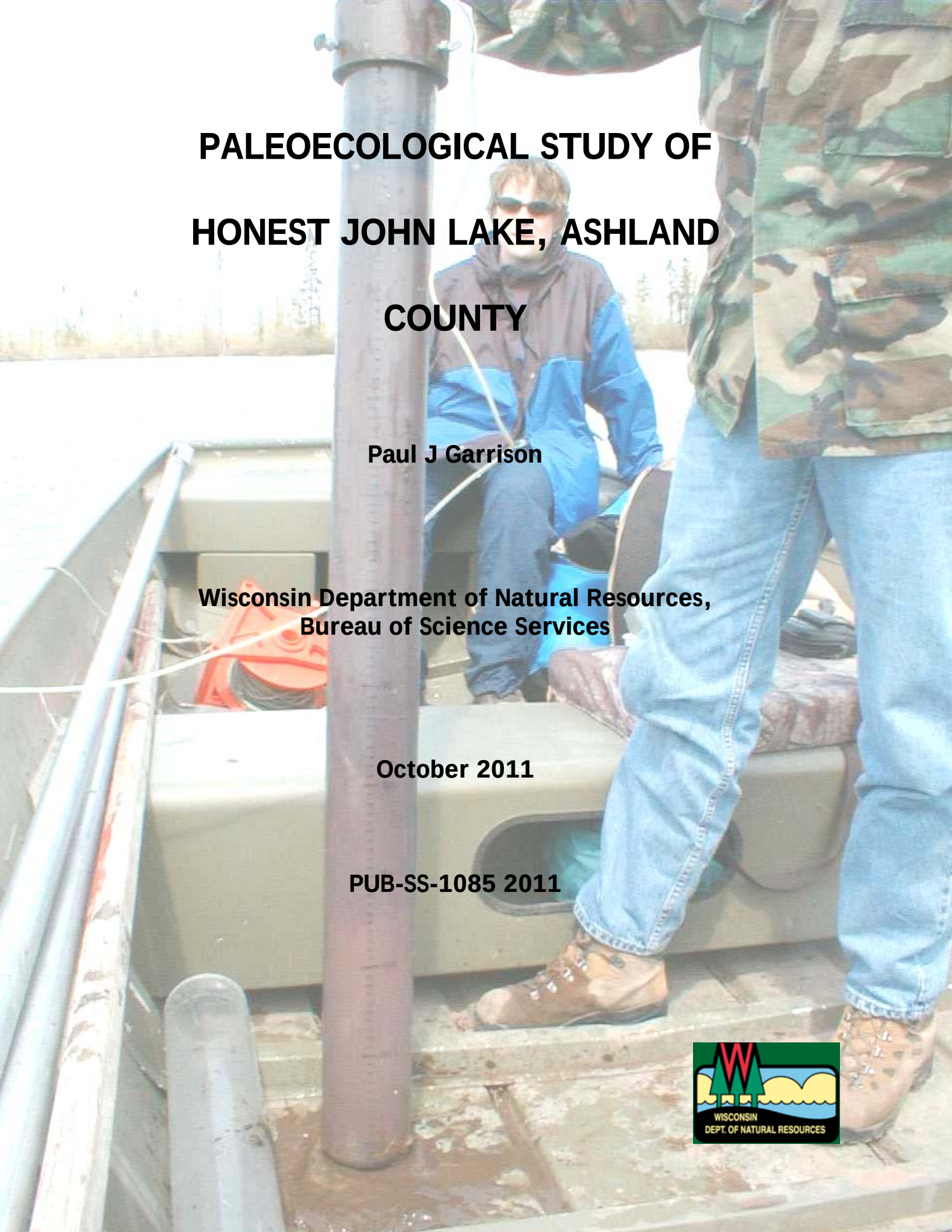

PALEOECOLOGICAL STUDY OF HONEST JOHN LAKE, ASHLAND COUNTY

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Introduction

Questions often arise concerning how a lake's water quality has changed through time as a result of watershed disturbances. In most cases there is little or no reliable long-term data. People often wonder about how a lake has changed, when the changes occurred and what the lake was like before the transformations began. Paleoecology offers a way to address these issues. The paleoecological approach depends upon the fact that lakes act as partial sediment traps for particles that are created within the lake or delivered from the watershed. The sediments of the lake entomb a selection of fossil remains that are more or less resistant to bacterial decay or chemical dissolution. These remains include diatom frustules, cell walls of certain algal species, and subfossils from aquatic plants. The chemical composition of the sediments may indicate the composition of particles entering the lake as well as the past chemical environment of the lake itself. Using the fossil remains found in the sediment, one can reconstruct changes in the lake ecosystem over any period of time since the establishment of the lake.

Honest John Lake, Ashland County, is a 93 acre lake with a maximum depth of 20 feet. A sediment core was collected from the deepest area on 28 May 2002. The location of the coring site was 46° 37.289" north and -91° 37.725 west in 20 feet of water (Figure 1). The core was collected with a piston corer having an inside diameter of 8.8 cm. The core was sectioned into 2 cm intervals for the entire core to a depth of 93 cm. The core was dated by the ^{210}Pb method and the CRS model used to estimate dates and sedimentation rate. The diatom community was analyzed to assess changes in nutrient levels and geochemical elements were examined to determine the causes of changes in the water quality.

Results and Discussion

Dating

In order to determine when the various sediment layers were deposited, the samples were analyzed for lead-210 (^{210}Pb). Lead-210 is a naturally occurring radionuclide. It is the result of natural decay of uranium-238 to radium-226 to radon-222. Since radon-222 is a gas (that is why it is sometimes found in high levels in basements) it moves into the atmosphere where it decays to lead-210. The ^{210}Pb is deposited on the lake during precipitation and with dust particles. After it enters the lake and is in the lake sediments, it slowly decays. The half-life of ^{210}Pb is 22.26 years (time it takes to lose one half of the concentration of ^{210}Pb) which means that it can be detected for about 130-150 years. This makes ^{210}Pb a good choice to determine the age of the sediment since European settlement began in the mid-1800s. Sediment age for the various depths of sediment were determined by constant rate of supply (CRS) model (Appleby and Oldfield 1978). Bulk sediment accumulation rates (g cm^{-2} yr^{-1}) were

calculated from output of the CRS model.

There can be problems with this dating technique. For example, when sediment has moved after it was deposited, large changes in sediment deposition over the last 150 years, and errors associated with lab analysis with sediments that are over 100 years old. For these reasons the accuracy of the ^{210}Pb dates is verified by other methods. These methods usually involve measuring parameters that are known to have been deposited at a certain time.

Cesium-137 (Cs^{137}) can be used to identify the period of maximum atmospheric nuclear testing (Krishnaswami and Lal 1978). The peak testing occurred by the USSR in 1963 and thus the ^{137}Cs peak in the sediment core should represent a date of 1963. The depth of this peak in the Honest John core is very close to the date of 1963 calculated by the ^{210}Pb model (Figure 1) indicating that the model results are very good.

Another sediment marker that can be used is the accumulation rate of stable lead. Much of the input to the lake is from bonded leaded gasoline. The decline of lead is largely the result of the discontinued use of leaded gasoline in the mid-1970s (Gobeil et al. 1995; Callender and Van Metre 1997). The

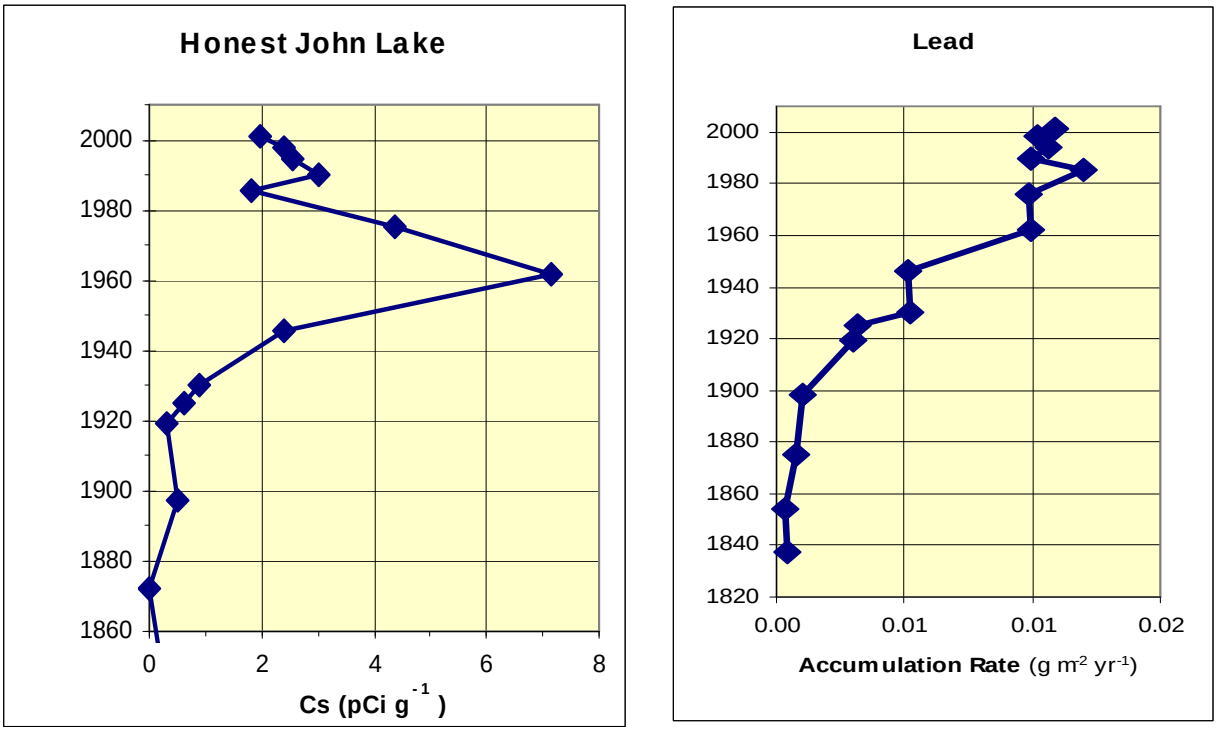

Figure 1. Profile of cesium-137 and stable lead in the core. The cesium peak is around 1963 which is the time of maximum input into the atmosphere. The peak for lead is the early to mid-1980s which further confirms the accuracy of the lead-210 model results.

lead peak often occurs in the early to mid-1980s. Figure 1 shows that the peak lead accumulation rate occurred during the mid-1980s.

Sedimentation Rate

The mean mass sedimentation rate for the last 200 years was 0.023 cm^{-2} yr^{-1}. This is near the median for the rate measured in 52 Wisconsin lakes (Figure 2). The rate is lower than many other lakes around the state. The partial reason for this lower rate is that the lake is a moderately softwater lake so there is not a significant amount of precipitation of calcium carbonate. The rate is higher than other similar lakes because fine red clay particles in the soil of the lake's watershed. The average linear rate for the same time period is 0.28 cm yr^{-1}, which equates to 0.1 inches per year.

To account for sediment compaction and to interpret past patterns of sediment accumulation, the dry sediment accumulation rate was calculated. The historical sedimentation rate was about 0.014 cm^{-2} yr^{-1} but the rate began to increase in the early part of the twentieth century (Figure 3). By the 1960s, the rate was twice the historical level. The rate significantly increased from the 1970s to the top of the core in the early 2000s. The highest sedimentation rate is at the upper part of the core with the peak occurring during the mid-1980s.

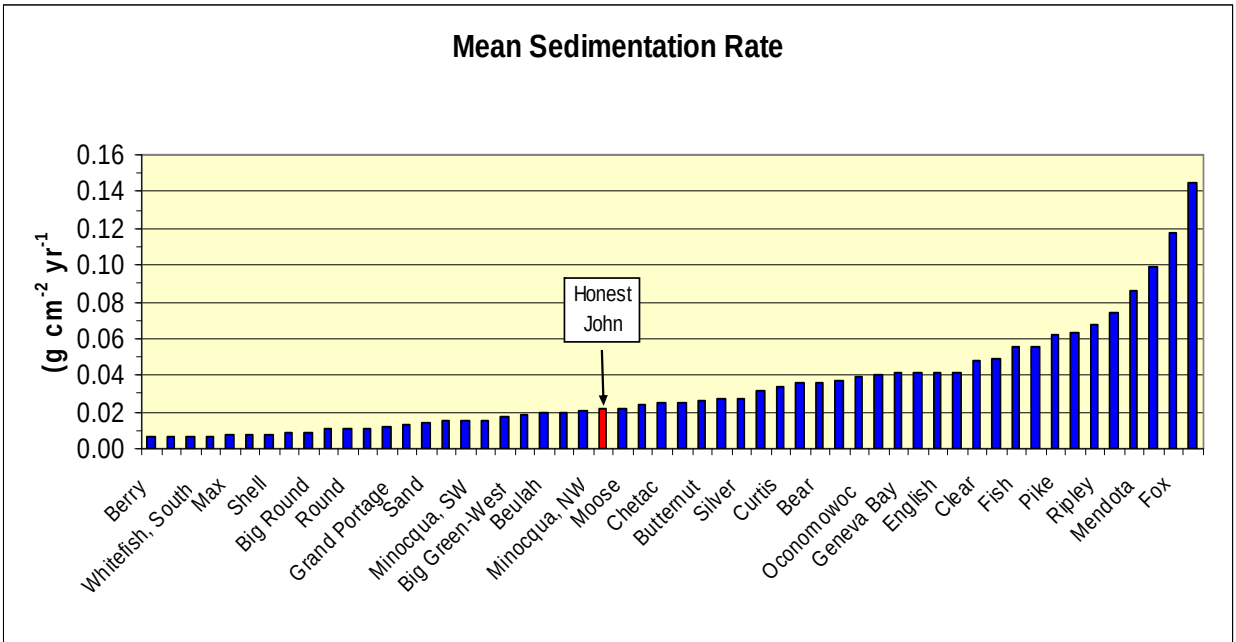

Figure 2. Mean sedimentation rate for the last 150 years for 52 Wisconsin lakes. The arrow indicates Honest John Lake. The rate in this lake is lower than many of the lakes. This is partially because the lake it is moderately softwater lake.

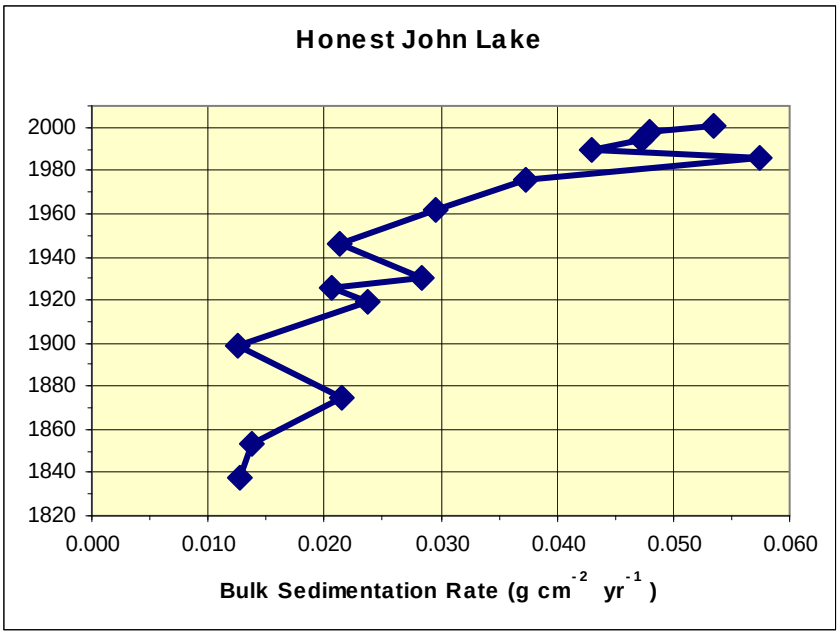

Figure 3. Sediment accumulation rate in Honest John Lake. The rate first began to increase in the early twentieth century but the highest rates have occurred during the last 3 decades.

Sediment Geochemistry

Geochemical variables are analyzed to estimate which watershed activities are having the greatest impact on the lake (Table 1). The chemicals aluminum and titanium are surrogates of detrital aluminosilicate materials and thus changes in their profiles are an indication of changes in soil erosion. Potassium is found in both soils and synthetic fertilizers. Therefore its profile will reflect changes both from soil erosion and the addition of commercial fertilizers in the watershed. Nutrients like phosphorus and nitrogen are important for plant growth, especially algae and aquatic plants. General lake productivity is reflected in the profiles of organic matter. The organic matter determination includes a number of elements, especially carbon.

Table 1. Selected chemical indicators of watershed or in lake processes.

Process	Chemical Variable
Soil erosion	aluminum, potassium, titanium
Synthetic fertilizer	potassium
Nutrients	phosphorus, nitrogen
Lake productivity	organic matter

The accumulation rate of selected geochemical elements was calculated by combining the elemental concentrations with the sedimentation rate. The accumulation rate gives an indication of how the deposition of the elements changed through time. This provides an indication of what watershed and inlake processes have occurred that consequently affected the lake ecosystem.

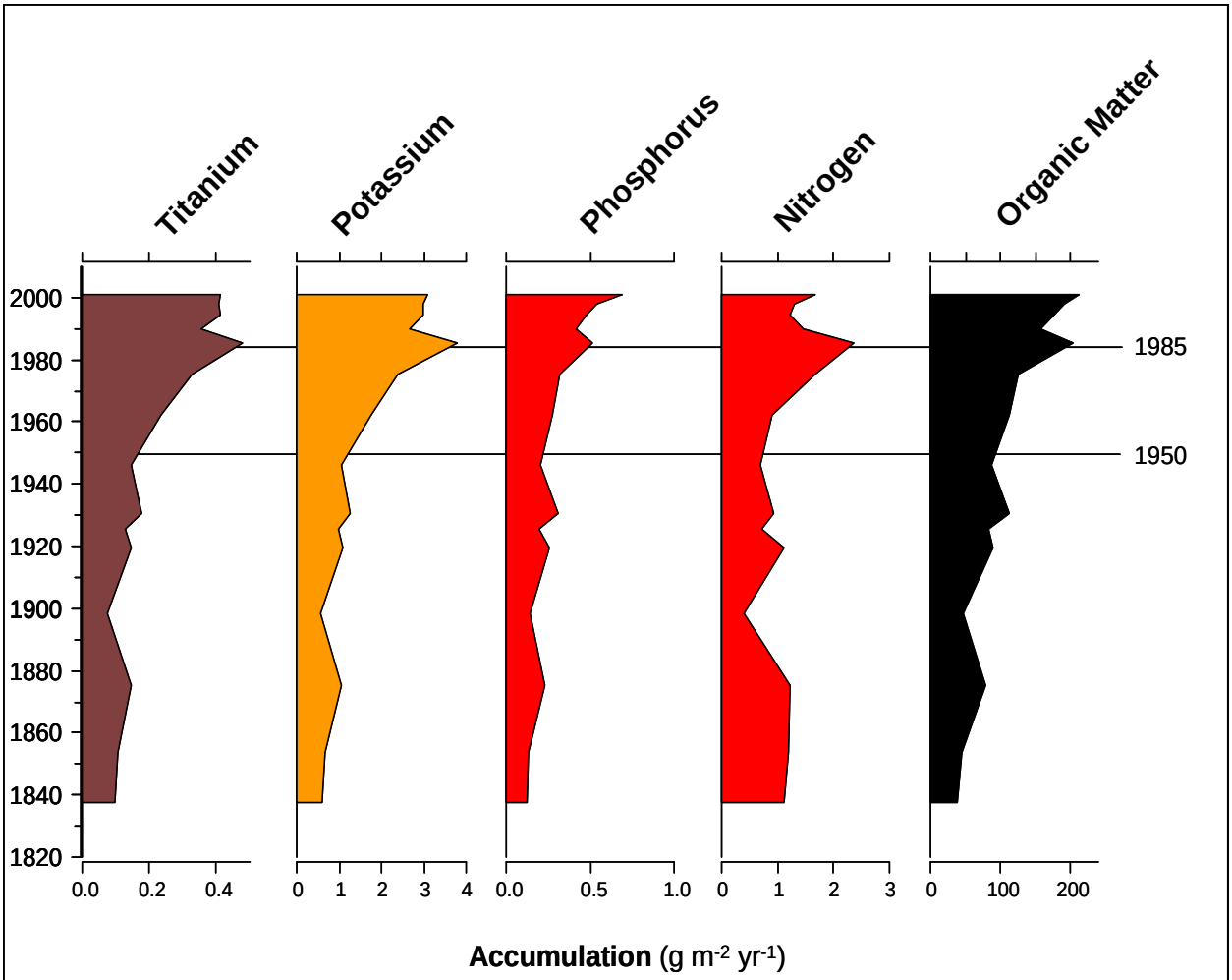

Figure 4. Profiles of the accumulation rate of selected geochemical elements. Titanium and potassium profiles are indicative of soil erosional rates in the watershed. Nitrogen and phosphorus profiles reflect changes in nutrient deposition rates. Organic matter indicates the general productivity of the lake.

The accumulation of titanium, which indicates soil erosion, was fairly constant from the mid-1800s until the 1950s. At that time soil erosion began to increase and peaked in the mid-1980s (Figure 4). Although the accumulation rate was slightly less during the 1990s it was still much higher than historical levels.

Although potassium can originate from soils or synthetic fertilizers, the profile is very similar to the titanium profile (Figure 4) and indicates nearly all of the potassium comes from soil erosion. The potassium profile indicates that there is minimal residue entering the lake from artificial fertilizers.

The phosphorus profile is generally similar to the titanium accumulation rate indicating that much of the phosphorus entering the lake comes from soil erosion. Accumulation rates increased minimally during the time period 1870-1950 but then the rate began to increase. The highest rate occurs at the

top of the core. Although the peak soil erosion occurred in the mid-1980s, the highest phosphorus rates are at the top of the core. The peak at the top of the core probably reflects the fact that phosphorus diagenesis was not complete when the core was collected. Diagenesis is the conversion of organic forms of a given element to its inorganic form through bacterial action. This typically happens with phosphorus, nitrogen, and carbon. All of these elements have high values in the topmost sample. It is likely that the concentration in the next depth down more accurately reflects the true accumulation rate.

The profile of nitrogen is somewhat different than the phosphorus accumulation rate. The peak rate was in the 1980s and likely was associated with soil erosion. Unlike phosphorus, the accumulation rate at the top of the core is similar to historical rates.

The organic matter profile, which indicates changes in the lake's general productivity is somewhat similar to the titanium and phosphorus profiles. The rates increase slightly during the period 1870-1950 but during the last half century the lake's productivity has increased the most. The close relationship between organic matter and phosphorus indicates that this essential nutrient is the most important nutrient in determining the lake's productivity.

Diatom Community

Aquatic organisms are good indicators of water chemistry because they are in direct contact with the water and are strongly affected by the chemical composition of their surroundings. Most indicator groups grow rapidly and are short lived so the community composition responds rapidly to changing environmental conditions. One of the most useful organisms for paleolimnological analysis is diatoms. They are a type of alga which possess siliceous cell walls and are usually abundant, diverse, and well preserved in sediments. They are especially useful as they are ecologically diverse and their ecological optima and tolerances can be quantified. Certain taxa are usually found under nutrient poor conditions while others are more common under elevated nutrient levels. They also live under a variety of habitats, which enables us to reconstruct changes in nutrient levels in the open water as well as changes in benthic environments such as aquatic plant communities. Figure 5 shows photographs of five diatom species that were found in the sediment core.

In the nineteenth century the diatom community was dominated by taxa that grow on substrates such as aquatic plants and the bottom sediments. These types of diatoms composed 75% of the community. This composition is common in shallow lakes with low nutrient concentrations. The most common taxa were *Pseudostaurosira brevistrata* and *P. trainorii* (Figures 5,6). The most common planktonic diatoms were *Aulacoseira nygaardii* and *A. ambigua*. The first diatom is found in lakes with low nutri-

ent levels (Camburn and Charles 2000) while the latter diatom is a common diatom in lakes of the Upper Midwest that possess low to moderate amounts of nutrients (Camburn and Kingston 19886; Kingston et al. 1990; Garrison 2005 a,b; Garrison 2006; Garrison 2008).

In the early part of the twentieth century the percentage of benthic diatoms began to decline as well as the oligotrophic diatom *A. nygaardii* (Figure 6). At this time there was an increase in *A. ambigua* as well as other *Aulacoseira* taxa. The decrease in benthic diatoms is an indication of an increase in phosphorus levels as the increase in planktonic diatoms and other algae reduces the amount of light reaching the bottom of the lake and benthic diatoms are out competed by algae floating in the open water. The percentage of planktonic diatoms continued to increase until 1950. In the early part of the twentieth century *A. tenella* increased and by 1930 it was replaced by *A. pusilla* (Figure 6). The first diatom is usually found in oligotrophic to slightly mesotrophic lakes (Siver et al. 2005) while *A. pusilla* is more common in higher nutrient waters (Denys et al. 2003). After 1950, the percentage of planktonic diatoms consistently comprised 50% of the diatom community. *Aulacoseira ambigua* continued to increase and *Pseudostaurosira parasitica* became more common. The first diatom seems to have a broad range of nutrient conditions being found low nutrient waters as well as those with moderate levels. Other studies have noted an increase in this taxa with increasing nutrient levels. The latter diatom grows attached to other algae and is usually found in mesotrophic lakes (Siver et al. 2005).

Diatom assemblages historically have been used as indicators of trophic changes in a qualitative way (Bradbury, 1975, Anderson et al., 1990, Carney 1982). In recent years, ecologically relevant statistical methods have been developed to infer environmental conditions from diatom assemblages. These methods are based on multivariate ordination and weighted averaging regression and calibration (Birks et al. 1990). Ecological preferences of diatom species are determined by relating modern lim-

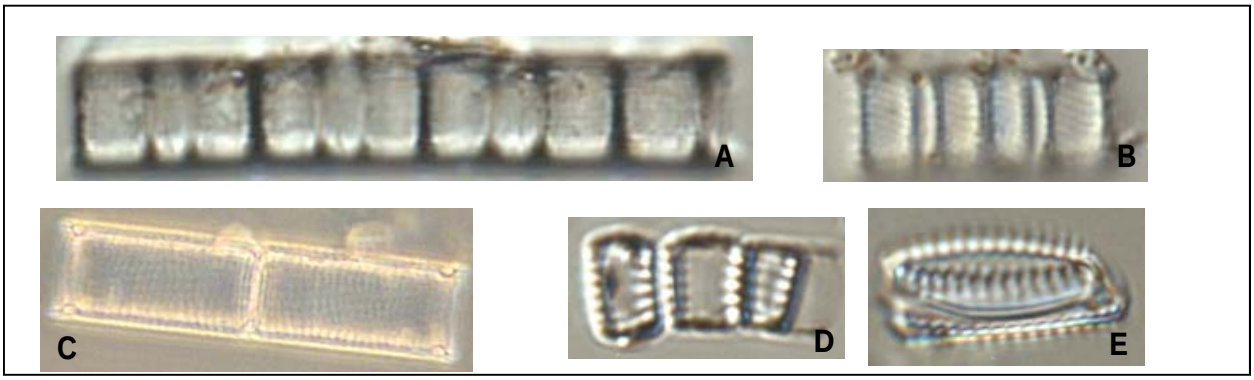

Figure 5. Photomicrographs of diatoms found in the sediment core. The diatom at the top left (A) *Aulacoseira nygaardii,* the diatom at the top right (B), *Aulacoseira pusilla*, and the diatom at the bottom left, (C) *Aulacoseira ambigua*, are found in the open water and indicate low to moderate nutrient levels. The diatoms at the bottom left (D) *Pseudostaurosira trainorii* and (E) *Pseudostaurosira brevistrata*, grow attached to substrates such as aquatic plants and on the lake bottom.

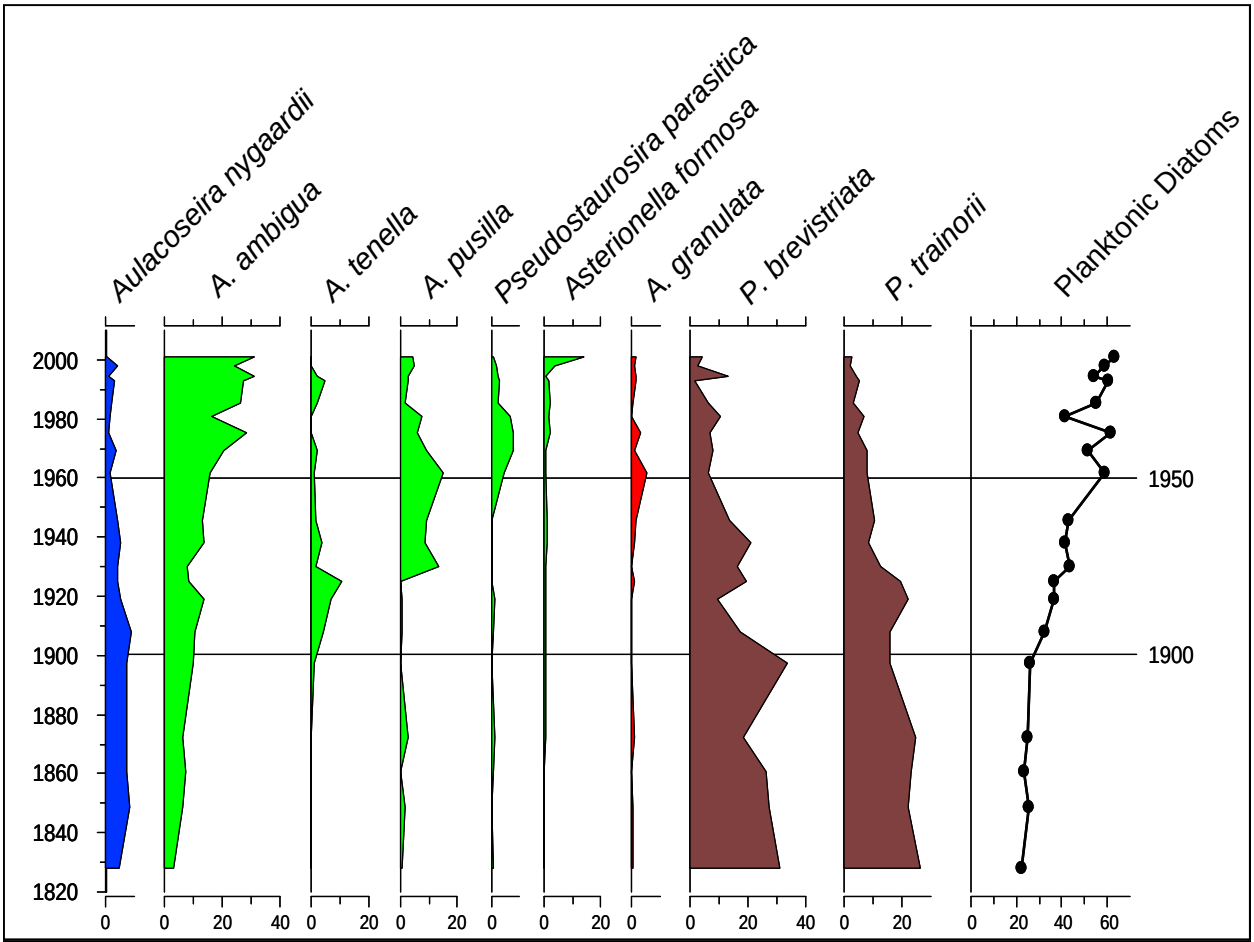

Figure 6. Profiles of common diatoms found in the core. The diatoms in blue are indicative of low nutrients while those in green are indicative of moderate nutrient levels. The brown colored diatoms grow attached to plants and on the sediments.

nological variables to surface sediment diatom assemblages. The species-environment relationships are then used to infer environmental conditions from fossil diatom assemblages found in the sediment core.

The diatom community was used to estimate the phosphorus concentrations in the lake during the last 2 centuries. The model estimates that historically the phosphorus concentration in Honest John Lake was 12-15 µg L^{-1} (Figure 7). During the 1930s there was a brief increase in phosphorus levels but concentrations returned to historical levels by 1940. During the 1960s there was a large increase in phosphorus and during the 1970s concentrations were 35-40 µg L^{-1} (Figure 7). Since 1970 the levels have varied but they generally remained about twice as high as historical concentrations. The highest concentration found in the core occurred at the top, where the concentration was about 45 µg L^{-1}.

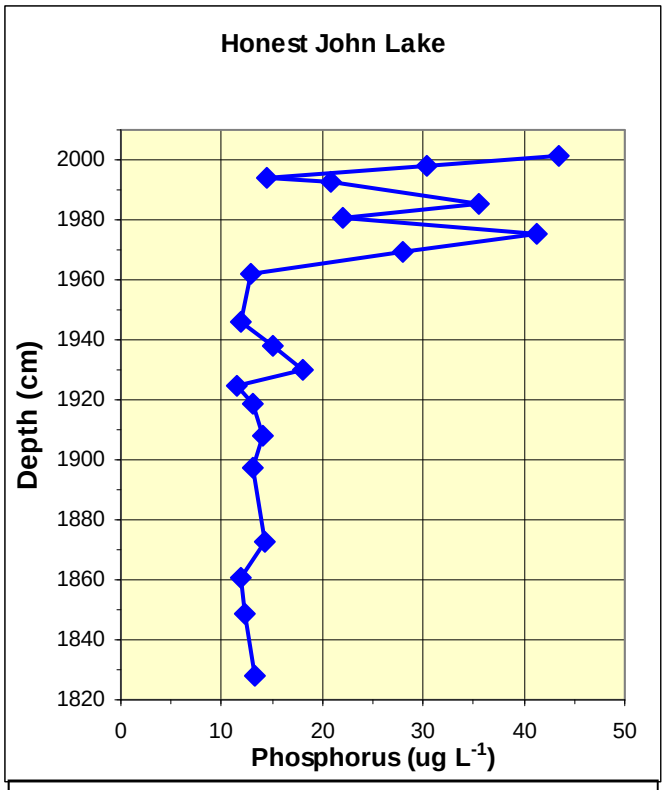

Figure 7. Estimated summer phosphorus concentrations based upon the diatom community.

Summary

The sediment core indicates that Honest John Lake has undergone some significant changes during the last 160 years. The greatest changes have occurred in the last 50 years. During this time the sedimentation rate has increased nearly four times over the historical rate (Figure 2). During this time period the phosphorus levels have also increased nearly 3 times over the historical concentration. This change has largely been driven by increased delivery of soil to the lake from the watershed. This is indicated by the increase in titanium which is only found in soil particles. This increased soil erosion has also brought phosphorus into the lake resulting in increased algal productivity. There has been a significant change in the diatom community from one dominated by diatoms that grow on the lake bottom or attached to substrates to a community with more planktonic diatoms (Figure 6). With the increase in phosphorus the water clarity has declined as algal productivity has increased.

Even though the greatest changes occurred after 1960, the diatom community composition showed that subtle watershed changes were impacting the lake starting at the beginning of the twentieth century.

The sediment core clearly shows that phosphorus levels in Honest John Lake are much higher at the present time compared with the nineteenth century. This increase likely results from disturbances in the watershed upstream of the lake. To improve the water quality of the lake and return its water quality to something closer to historical conditions, it will be necessary to reduce soil inputs into the lake.

- The mean sedimentation rate for the last 150 years in Honest John Lake was near the median measured in 52 Wisconsin lakes. This was partially because it is a moderately softwater lake and relatively shallow.

- The historical sedimentation rate was about 0.014 cm^{-2} yr^{-1} but the rate began to increase in the early part of the twentieth century and the highest rate occurred during the last 20 years.

- The major input of geochemicals to the lake was from soil erosion. The erosional rates significantly increased after 1960 and remain high since then.

- Phosphorus input to the lake showed a similar trend as titanium indicating that soil erosion is the dominant source of phosphorus to the lake.

- The diatom community indicates a small increase in nutrients after 1900 but the greatest increase occurred after 1960.

- The historical phosphorus concentration in the lake was 12-15 µg L^{-1}. In response to increased phosphorus delivery from the watershed in the form of soil particle, the lake phosphorus concentrations increased to around 40 µg L^{-1} after 1960 and this concentration has been maintained.

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